

Applications of Powder Metallurgy Aluminums for Automotive Valve-Trains

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ABSTRACT

Current applications of powder metallurgy (PM) aluminum for automotives are predominantly focused on cam caps. Metal Powder Products Company (MPP) pioneered the cam cap production and is the leading producer of the parts in the world. For moving valve-train parts, the lighter aluminum not only reduces weight leading to lower fuel consumption, but also reduces moment inertia of the parts leading to performance improvement. This study examines the properties of some PM aluminum materials having higher wear resistance, improved fatigue strength and stiffness, in comparison with the cast aluminums and some ferrous PM materials. The results suggest that the PM aluminums are feasible substitutes for replacing the cast aluminums and the ferrous PM materials for the valve-train components.

INTRODUCTION

Application of powder metallurgy (PM) aluminum for automotive use was started with the adoption of the PM aluminum cam caps, replacing those made by aluminum castings and expensive secondary machining. Metal Powder Products Company (MPP) pioneered the PM cam cap production and is the leading producer of the pressed and sintered PM aluminum structural components in the world. The company started making the aluminum components in 1973 and launched the automotive components production in 1991. The company is making over a dozen types of cam caps which are used by a number of auto-makers around the world. More than 50 million cam caps have been shipped without functional failures. In recognition of the technological achievements, MPIF awarded the Grand Prize to the company for a PM aluminum camshaft bearing cap in the automotive engine category of the 2006 Powder Metallurgy Design Excellence Awards Competition. Application of the PM aluminums is now entering a new phase, with new applications for the automotive valve-train components, such as pulleys,

sprockets, VVT components and other reciprocating parts [1-3]. For moving parts in automotive engines, the lighter material not only reduces weight leading to lower fuel consumption, but also reduces moment inertia of the parts leading to performance improvement.

In general, the commercial PM aluminum materials offer mechanical properties that are equivalent to or better than that of the cast aluminum materials. Lowering cost is one of the main reasons for substituting the components made by the aluminum castings for the PM aluminum components. Powder metallurgy technology provides efficient means of fabricating net-shape or near net-shape components in mass production, enabling machining to be minimized, hence reducing the costs. For instance, cost of a powder metallurgy double hump cam cap is more than 20% lower than that made by the casting and secondary machining, despite much lower raw material cost for the casting [4]. The PM technology allows small and intricate features to be produced, leading to the integrated and more complex oil tunnels in the PM cam cap than that of the die casting cam cap. In addition, the PM technology produces more uniform microstructure than those made by conventional ingot metallurgy (I/M) that often contain segregations of pore or alloying elements, which often results in improved mechanical and corrosion properties. The aluminum PM materials can therefore compete with the conventional aluminum casting alloys, as well as with other materials, for cost-critical applications.

The aluminum alloys, however, do have limitations compared with the competitive materials. For instance, Young's modulus of aluminum materials (~80GPa) is significantly lower than that of ferrous alloys (~210GPa) and titanium alloys (~112GPa). At present, 2000 series PM aluminum materials are widely used for the pressed and sintered structural parts. The materials have good strength, good ductility and excellent processing characteristics. But, their wear resistance and stiffness are limited. The addition of ceramic particulates to the PM aluminum materials significantly improves wear, the stiffness, the fatigue and the high temperature

properties of the materials [5-10]. In general, the properties increase with the fraction of the reinforcements. The Young's modulus of an aluminum powder metallurgy alloy reinforced with 20%Al₂O₃ particulate is reported to have been increased by over 30% than the based alloy [10]. The shape and size of the reinforcement have a significant effect on the wear and fracture toughness of the reinforced materials [11-13, 16, 22]. The fatigue strength of a 2024 aluminum alloy reinforced with 10%SiC particulate is found to increase with decreasing the reinforcement particle size [13, 15-17]. Similar to the ceramics, the additions of large amounts of silicon to aluminums can significantly increase the wear resistance and the stiffness of the materials [18-21]. The distribution and size of the silicon particles in the microstructure determines the wear and fatigue behavior of the materials. Powder metallurgy Al-Si alloys exhibit a more uniform microstructure, and the size and amount of silicon particles are better controlled, preventing the silicon from segregation that leads to undesirable wear and fatigue performance. As many potential applications in the automotive valve-train components are subjected to wear and cyclic load, the improvement in the properties enables the PM aluminums to be used for more demanding applications, such as pulleys, sprockets and other valve-train components.

EXPERIMENTAL

The powder metallurgy aluminum materials used for this investigation include conventional 2000 series PM aluminum materials, ceramic particulates reinforced PM aluminums and PM aluminum containing up to 15% silicon. The powder metallurgy aluminum materials were pressed at pressures up to 50tsi and sintered under inert gas protections for up to 60 minutes. The mechanical properties of the materials were examined on the as-sintered (T1) and artificially aged (T6) samples. The property of the PM aluminum was compared with the cast aluminum materials and some ferrous PM materials.



Fig. 1 Aluminum cam caps, including the winner of the 2006 Powder Metallurgy Design Excellence Awards Competition (left front), made by Metal Powder Products Company (MPP) who pioneered the cam cap production and is the leading producer of the parts in the world.

RESULT AND DISCUSSION

STIFFNESS - The modulus as a function of the elongation for the MPP aluminum powder metallurgy materials and the cast aluminum materials is shown in the Fig. 2. Most of the aluminum materials, including the 2000 series MPP510 and the cast aluminum materials have a Young's modulus in range of 70-80GPa. However, the reinforced PM aluminum materials offered by MPP, such as the MPP915 and MPP1404 have a significantly higher Young's modulus, 90-105GPa. A high modulus represents a higher stiffness. In addition, the fatigue strength of the reinforced materials is also significantly higher than the cast aluminums. For example, the fatigue endurance limit (10 million cycles) of the MPP915 in a fully reversed tension-compression test reached over 100MPa. While the fatigue endurance limits for the base PM aluminum, the MPP510 and the cast aluminum materials is only 65-80MPa.

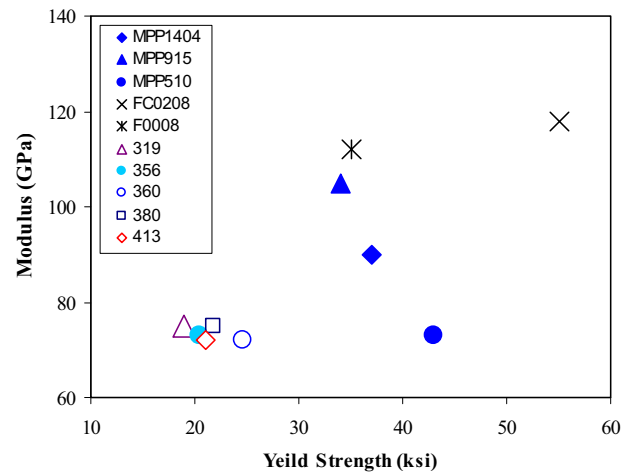


Fig. 2 Modulus and the yield strength of the MPP aluminum powder metallurgy materials, the cast aluminum materials [23, 24] and some ferrous PM materials [25].

HARDNESS - Wear resistance is an important factor for engineering design. Many potential automotive valve-train components applications, such as pulleys, sprockets and other reciprocating parts, are subjected to wear and cyclic load. Hence, the wear resistance and fatigue strength of the PM aluminum materials are critical for the applications. Hardness along with fracture toughness is one of the important indications of the wear resistance for metallic materials. In general, the higher the hardness and the fracture toughness, the more wear resistant the material is [18]. However, it is the hardness of the contacting asperities and not the bulk hardness that controls the wear rate [19]. Fig. 3 shows the hardness as a function of the elongation for the MPP aluminum PM materials and the cast aluminum materials. Most of the cast aluminum materials have modest hardness, ranging from 20 to 55HRB. The powder metallurgy aluminum materials have a much wide range of the hardness. The wider hardness range is due to the flexibility of the powder metallurgy technology in manipulating the alloy chemistry, increased density and the microstructures of the PM materials. The